NPOESS Cross-track Infrared and Microwave Sounder Suite (CrIMSS) EDR Retrieval Algorithm and its Performance Assessment

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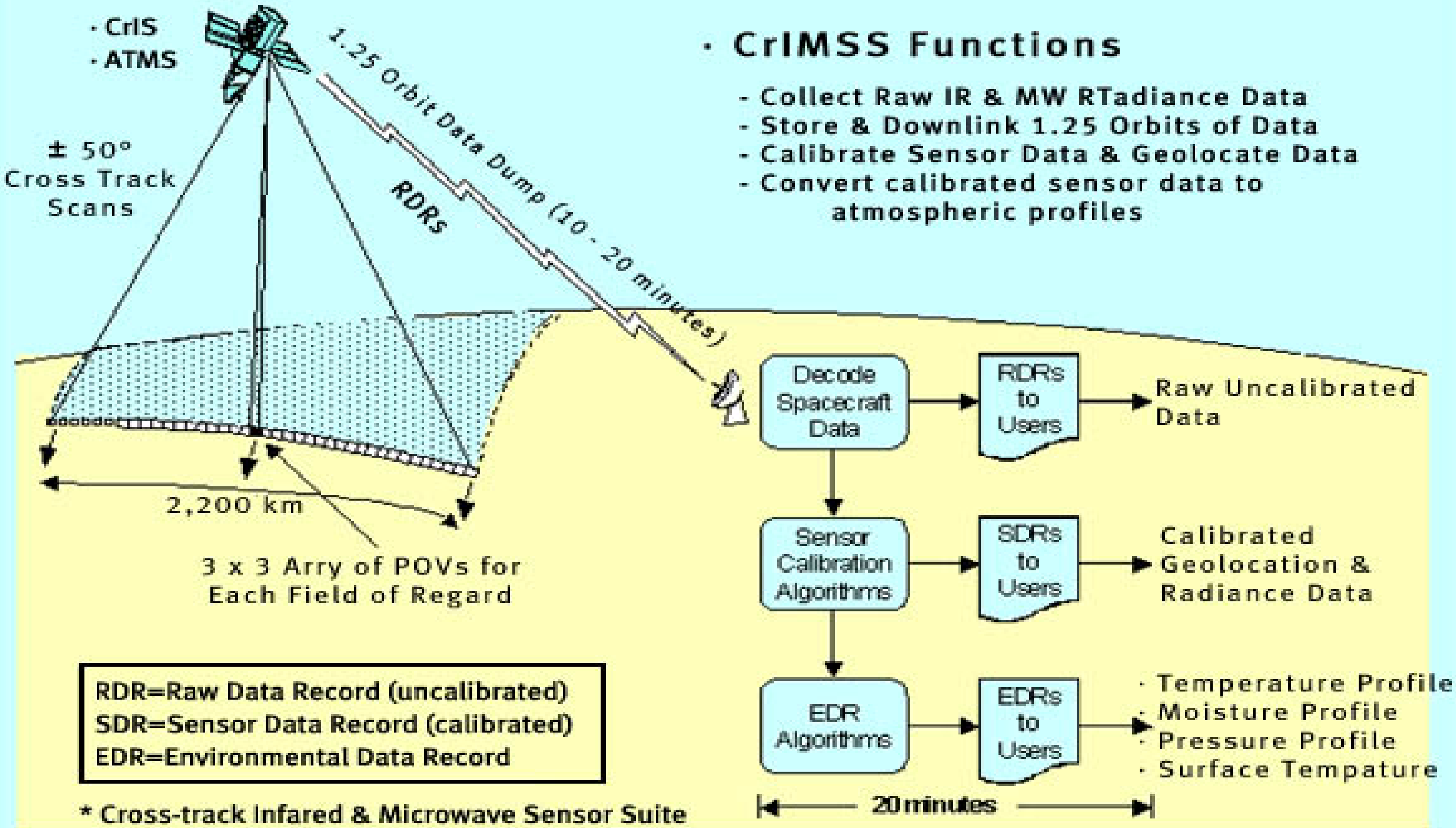
Overview

- CrIMSS instruments
- CrIMSS EDR algorithm overview
- Test methodology and test data generation
- Test results
- Summary

CrIMSS Products Include Atmospheric Profile EDRs and IR and MW SDRs

CrIMSS consists of two sounding instruments and produces three NPOESS Environmental Data Record (EDR) products



- **CrIMSS Functions**
  - Collect Raw IR & MW RTadiance Data
  - Store & Downlink 1.25 Orbits of Data
  - Calibrate Sensor Data & Geolocate Data
  - Convert calibrated sensor data to atmospheric profiles

RDR=Raw Data Record (uncalibrated)
SDR=Sensor Data Record (calibrated)
EDR=Environmental Data Record

* Cross-track Infared & Microwave Sensor Suite

http://www.ipo.noaa.gov/Technology/crimss_summary.html

CrIS and ATMS Instruments Overview

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CrIS Instrument Characteristics

Spectral Range	
LWIR Band MWIR Band SWIR Band	650-1095 cm-1 1210-1750 cm-1 2155-2550 cm-1
Spectral Resolution	
LWIR Band MWIR Band SWIR Band	<0.625cm-1 <1.25cm-1 <2.50cm-1
Registration	
Band-to-Band Co-Reg FOV Jitter Mapping accuracy	<1.4% <50 urad/axis <1.5 km
Field-of-View (FOV)	
# of FOV FOV Diameter (round) FOV shape match	3X3 14 km <0.05%

http://www.ipo.noaa.gov/Technology/crimss_summary.html

ATMS Instrument Characteristics

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CH	Frequency	Band Width	NEdT	Beam Width
1	23.8	0.27	0.5	5.2
2	31.4	0.18	0.6	5.2
3	50.3	0.18	0.7	2.2
4	51.76	0.40	0.5	2.2
5	52.8	0.40	0.5	2.2
6	53.596±0.115	0.17	0.5	2.2
7	54.40	0.40	0.5	2.2
8	54.94	0.40	0.5	2.2
9	55.50	0.33	0.5	2.2
10	57.290334	0.33	0.75	2.2
11	57.290334±0.217	0.078	1.0	2.2
12	57.290334±0.3222±0.048	0.036	1.0	2.2
13	57.290334±0.3222±0.022	0.016	1.50	2.2
14	57.290334±0.3222±0.010	0.008	2.2	2.2
15	57.290334±0.3222±0.0045	0.003	3.60	2.2
16	88.2	2.0	0.3	2.2
17	165.5	3.0	0.6	1.1
18	183.31 ± 7	2.0	0.8	1.1
19	183.31 ± 4.5	2.0	0.8	1.1
20	183.31 ± 3	1.0	0.8	1.1
21	183.31 ± 1.8	1.0	0.8	1.1
22	183.31 ± 1	0.5	0.9	1.1

CrIMSS EDR Retrieval Algorithm Overview

The iterative physical CrIMSS EDR retrieval algorithm (developed by AER)

- Applies a modified maximum likelihood inversion model to search for a set of atmospheric and surface parameters that can feed into a forward model to "produce" the radiance data measured by CrIMSS
- The solution is further constrained to be physically feasible, and is defined to minimize the following cost function:

$$(\hat{R}-R)^T S_R^{-1}(\hat{R}-R)+(\hat{X}-X_a)^T S_X^{-1}(\hat{X}-X_a)$$

  - R^ and R: computed and measured radiances; X^ retrieved geophysical parameters
  - S_R: radiance error covariance--including both measurement and forward model errors
  - Xa: a *priori;* S_X: covariance– to be derived from global model/in-situ databases. They are stratified by surface type to improve algorithm performance

Key features of the CrIMSS EDR algorithm include:

- Empirical Orthogonal Function (EOF) transformation of retrieved variables that provides inversion stability and speed
- Iterative minimization that accounts for non-linearity
- Fast and accurate RTMs (Optimal Spectral Sampling Radiative Transfer models)

CrIMSS EDR Retrieval Algorithm Overview (cont'd)

The CrIMSS EDR algorithm consists of 7 modules

- Initialization
- Input and Pre-processing
- Microwave-only (MW) Retrieval
- Scene Classification
- Microwave and Infrared Combined (MW+IR) Retrieval
- Quality Control
- Output and Post-processing

The retrieved parameters include

- Temperature profile (reconstructed from 20 temperature EOFs)
- Moisture profile (reconstructed from 10 moisture EOFs)
- Surface temperature
- Surface MW emissivity (reconstructed from 5 MW emissivity EOFs)
- Surface IR emissivity (at 12 frequency hingepoints)
- Surface IR reflectance (at 12 frequency hingepoints)
- MW cloud top pressure and cloud liquid water path
- Ozone profile (reconstructed from 7 EOFs)

NGST Algorithm Performance Testing/Verification Methodology

Northrop Grumman Space Technology (NGST) developed rigorous test procedure and high fidelity test data to ensure algorithm performance assessment accuracy

- Verify the tests performed by sensor/algorithm subcontractors
- Extend the tests performed by sensor/algorithm subcontractors
- Focus on EDR global performance
- Use both simulated and proxy (real) test data

Simulated Test Data

- Primary test data source for pre-launch EDR algorithm performance assessment and characterization
- Generated using NGST's end-to-end simulation system which employs:
  - A compilation of global/regional environmental scene datasets
  - Validated radiative transfer models
  - Rigorous models of sensors and spacecraft platforms

Proxy Test Data

- Complementary test data source for assessing EDR algorithm performance under real world phenomenology and actual sensor/spacecraft performances
- Generated using:
  - Calibrated heritage sensor data records with similar characteristics
  - A validated model to map heritage SDRs to NPOESS SDRs
  - A validated source of "truth" EDR datasets

EDR Performance Assessment Using End-to-End Simulated Sensor Data

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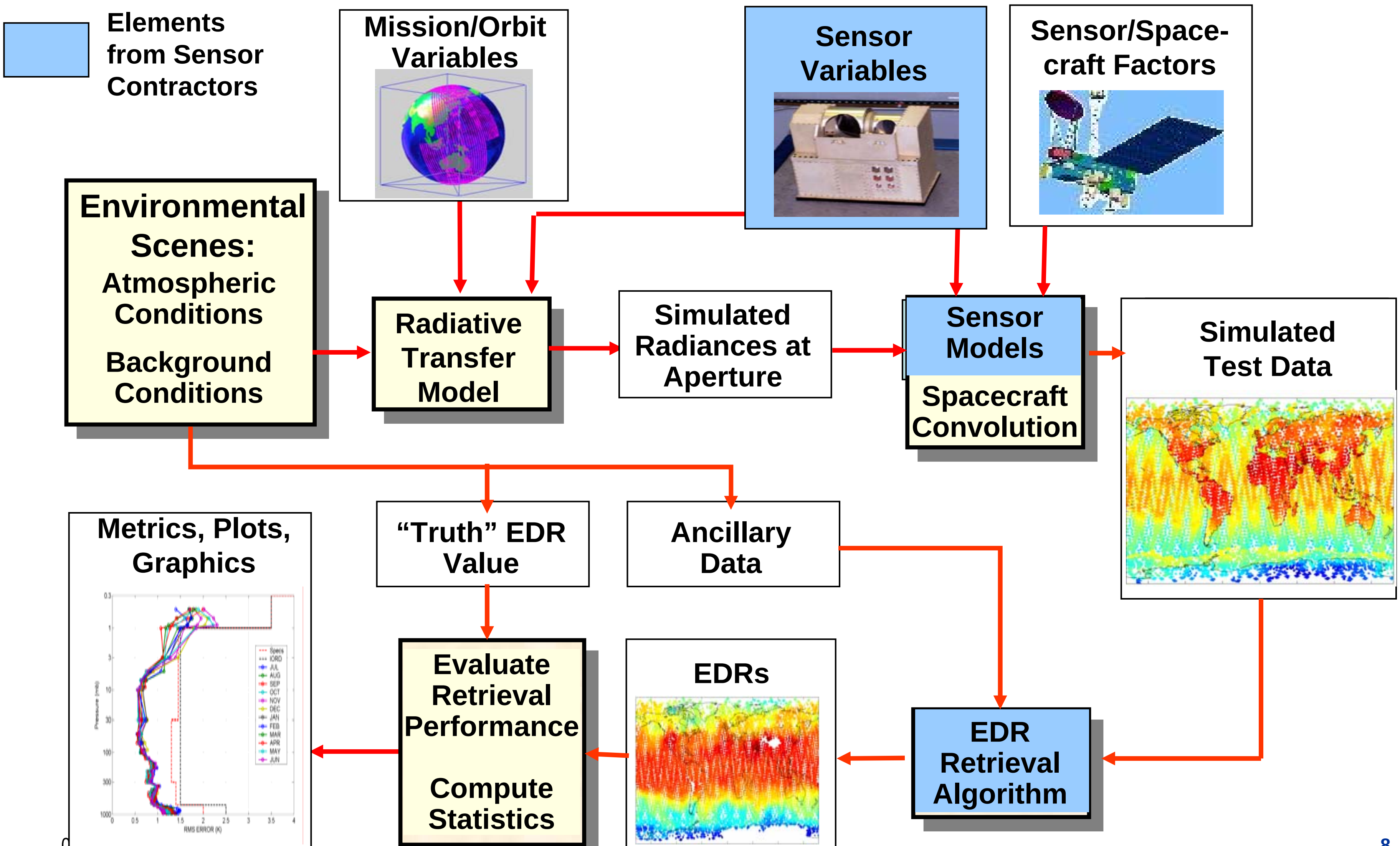
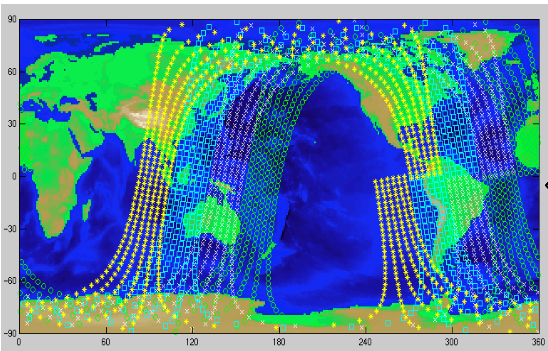
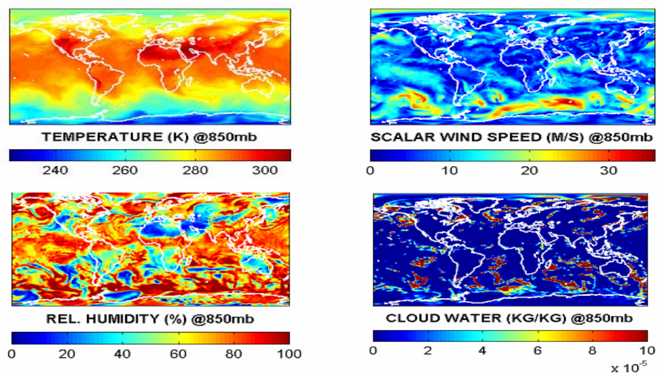


Sampling Global Data to Produce Test Datasets for EDR Assessment

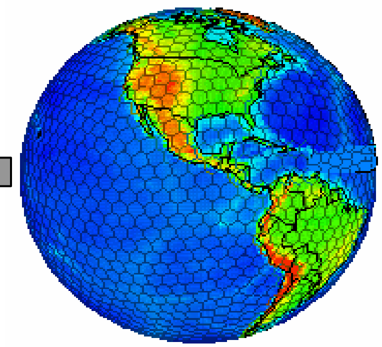
Sampling Based on NPOESS Orbits & Sensor Geometry



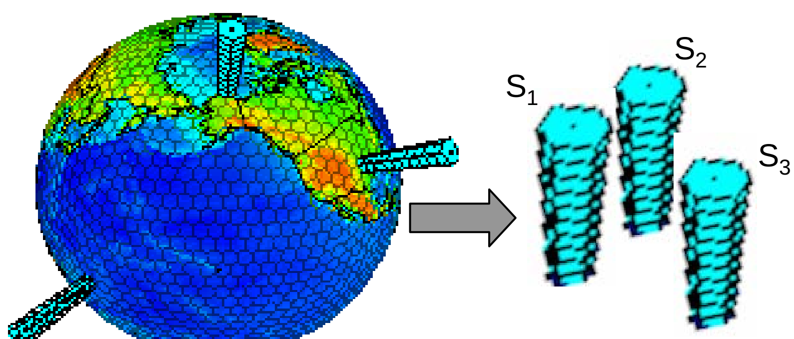
4D Distribution of Atmosphere And Surface Conditions



NCEP GDAS & Climatology Data



1D Geophysical Properties at Sampled Locations & Times



Sampling Approach:

- Distribution of atmosphere/surface conditions in space & time is provided by NCEP & climatology
- Sampling of global positions, times and solar/sensor viewing angles is obtained by “flying” sensor for NPOESS 1330, 1730 and 2130 orbits
- Produces ~700,000 atmosphere/surface conditions representative of what the sensor should observe on orbit

CrIMSS Test Data Generation: Physical Scenes

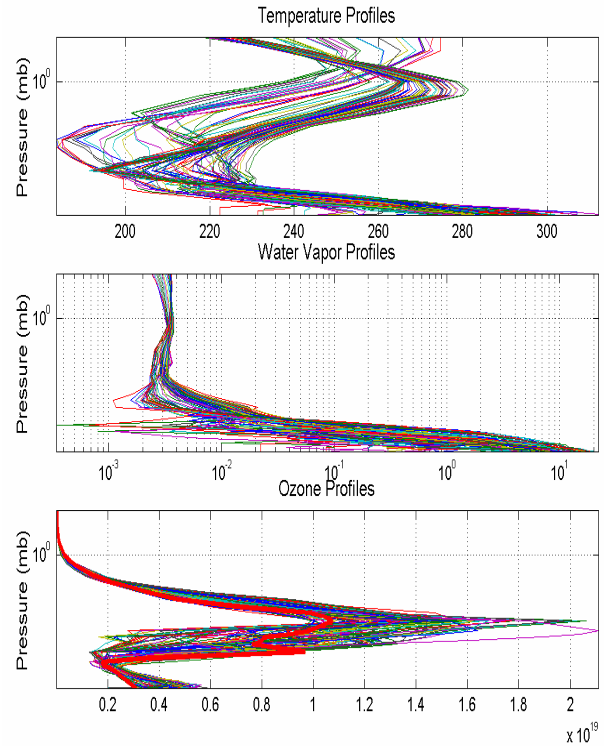
Profiles: Generated on a fixed-pressure grid from 4x daily NCEP tropospheric datasets (temperature, moisture, ozone, cloud liquid water), daily NCEP stratospheric datasets (temperature), UARS climatology database (moisture, ozone) and CIRA-86 climatology database (temperature)

Clouds: generated from NGES's CSSM using NCEP cloud liquid water profiles and other meteorological data as input

IR emissivity/reflectance: a high-resolution database compiled by Photon Research Associate

MW emissivity:

- Over ocean: generated using Weilheit's ocean emissivity model from NCEP wind speed and temperature
- Over land: generated using Grody's model



Captured the seasonal and diurnal variability of environmental conditions

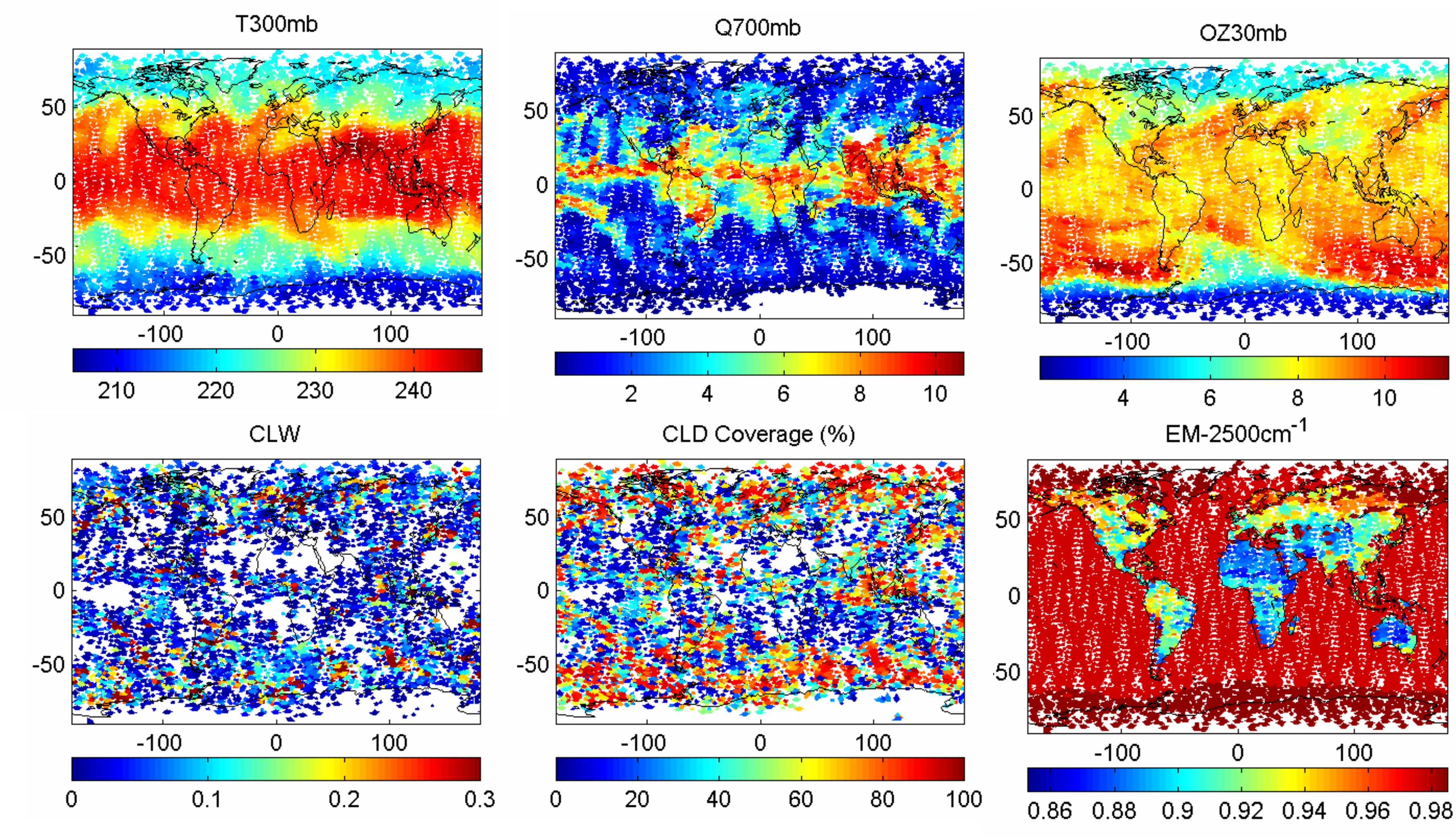
- Twelve days of global scenes, one day for each month
- Actual sensor scanning geometry from three orbits: 1330, 1730, and 2130

Captured the vertical and/or spatial variability of atmosphere and surface properties

- Self-consistent temperature, moisture, ozone, and cloud liquid water profiles
- "Consistent" IR clouds simulated from CSSM using cloud water profile as input
- Spectral variability of surface emissivity represented at 28 frequency hinge points

Simulated Consistent and Realistic Environment Scenes

NGST Global Test Dataset No. 010701



CrIMSS Test Data Generation: Sensor Effects

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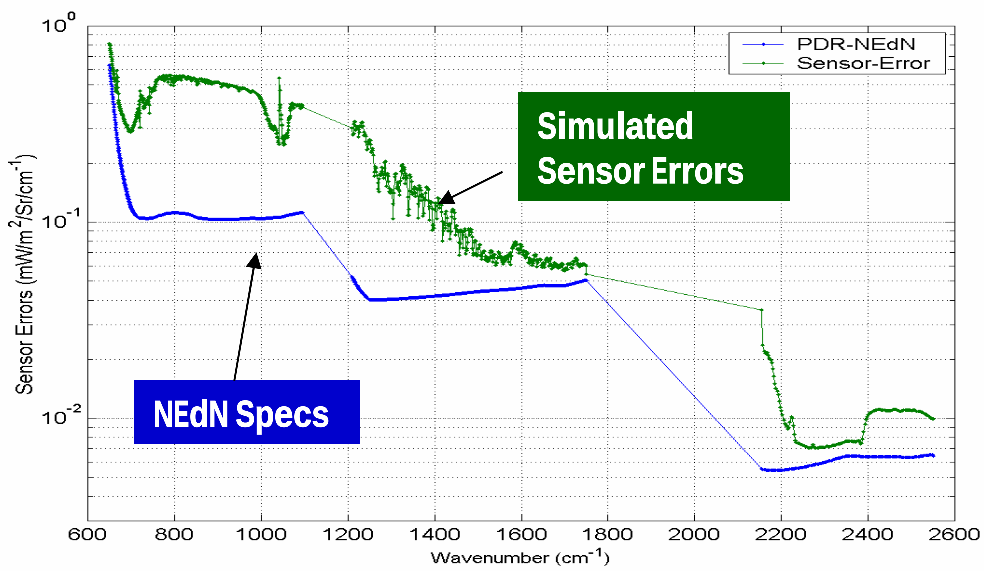
CrIS sensor effects are simulated using CrIS sensor subcontractor's sensor characterization input. Magnitude of the simulated sensor effects is several times larger than the sensor noise (NEdN) alone

- Noise: Nominal CrIS Sensor NEdN Specs
- Jitter: noise-like error at LOS jitter
- ILS Instability
- Spectral Uncertainty
- Radiometric Uncertainty:
- Scene-dependent Errors
  - Co-Registration

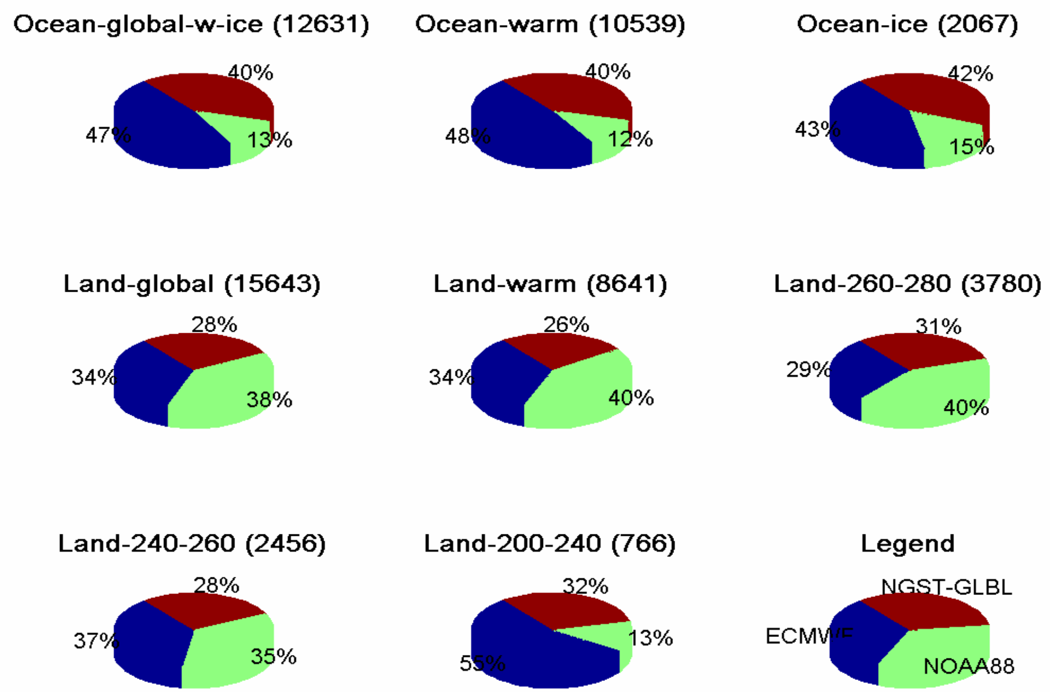


Simulated ATMS sensor effects include NEdT and noise reduction associated to the re-mapping of ATMS FOV to CrIS FOR

Derivation of *a priori* from a Diversified Global Training Dataset

Compiled one exhaustive training dataset by combining three global datasets of different origin and characteristics to mitigate dependence of CrIMSS EDR products on any single data data model or source

- NGST(NCEP) global dataset (9413 profiles sampled from 4 test datasets)
- ECMWF dataset (11314 profiles sampled from ECMWF 60L-SD)
- NOAA88B dataset (7547 profiles from NOAA88B -- upper atmosphere moisture threshold increased from 2E-4 to 3.4E-3 g/kg)



IR/MW emissivity databases and models:

- JPL's ASTER Spectral Emissivity Library and UCSB's MODIS Spectral Emissivity Library
- Wilheit's (ocean) and English's (land) MW emissivity models (will be extended/replaced with NGST first principle emissivity models)

Current Performance Estimate: Moisture Profile EDR (AVMP)

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AVMP meets measurement uncertainty requirements at all altitudes and under both clear and clouds conditions, with significant amounts of margin ranging from 20.9% to 84%.

Paragraph	Subject	Specified Values	Estimated Values	Margin
40.2.1-9	1. Clear, Surface to 600 mb	14.10%	8.00%	43.30%
40.2.1-10	2. Clear, 600 mb to 300 mb	13.80%	7.40%	46.40%
40.2.1-11	3. Clear, 300 mb to 100 mb	11.7% (or 0.05g/kg)	0.008k/kg	84%
40.2.1-12	4. Cloudy, Surface to 600 mb	15.80%	12.50%	20.90%
40.2.1-13	5. Cloudy, 600 mb to 300 mb	17.10%	10.50%	38.60%
40.2.1-14	6. Cloudy, 300 mb to 100 mb	16.4% (or 0.05g/kg)	0.015g/kg	70%

Current Performance Estimate: Temperature Profile EDR (AVTP)

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AVTP meets measurement uncertainty requirements at all altitudes and under both clear and cloud conditions, with significant amounts of margin ranging from 14.4% to 50.6%.

Paragraph	Subject	Specified Values	Estimated Values	Margin
40.2.2-26a	1. Clear, Surface to 300 mb	0.9 K / 1 km Layer	0.77K	14.4%
40.2.2-27	4. Clear, 300 mb to 30 mb	0.98 K / 3 km Layer	0.7K	28.6%
40.2.2-28a	5. Clear, 30 mb to 1 mb	1.45 K / 5 km Layer	1.25K	13.8%
40.2.2-29	8. Clear, 1 mb to 0.5 mb	3.5 K / 5 km Layer	1.73K	50.6%
40.2.2-30	10. Cloudy, Surface to 700 mb	2.0 K / 1 km Layer	1.30K	35%
40.2.2-31	11. Cloudy, 700 mb to 300 mb	1.4 K / 1 km Layer	0.98K	30%
40.2.2-32	12. Cloudy, 300 mb to 30 mb	1.3 K / 3 km Layer	0.90K	30.8%
40.2.2-33a	13. Cloudy, 30 mb to 1 mb	1.45 K / 5 km Layer	1.22K	15.9%
40.2.2-34	16. Cloudy, 1 mb to 0.5 mb	3.5 K / 5 km Layer	1.78K	49.1%

Additional Testing of CrIMSS EDR Algorithm Using Proxy Data

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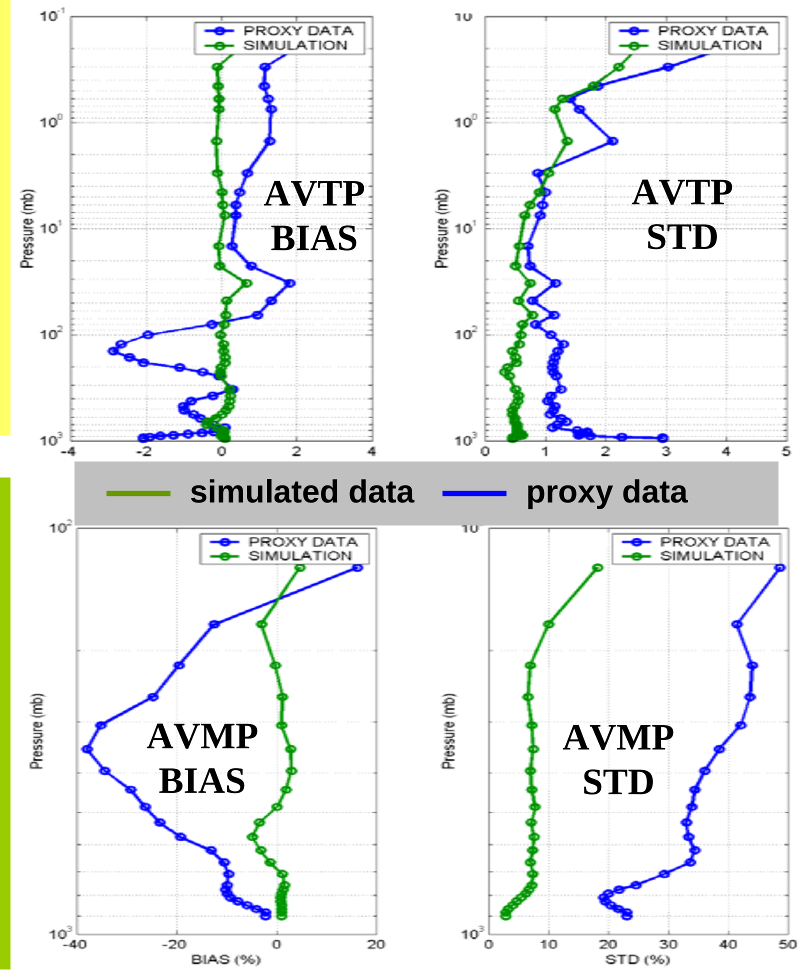
The CrIMSS algorithm demonstrated promising performance on the limited tests using proxy data

- The proxy data were generated from the EOS sensors (AIRS/AMSU/HSB) measurements (courtesy of Joel Susskind, GSFC)
- One-day's worth of data for 01/15/2003 were provided
- Seven night-time, ocean, least-cloudy scenes (6 min each) were used to test the CrIMSS algorithm's performance. They are co-located to NCEP reanalysis data ("truth") at 0600,1200,1800GTC (within 1hr)



- The quality of retrieved AVTP is very good, and breakdowns occur only near the surface
- The large errors in AVMP in part could be due to uncertainty in the "truth"
- The biases are likely caused by discrepancy between data and RTM
- The MW-only retrieval performance (not shown) matches very well with that obtained from the simulated test data

Tools Developed to Analyze Test Data and Results in Great Detail

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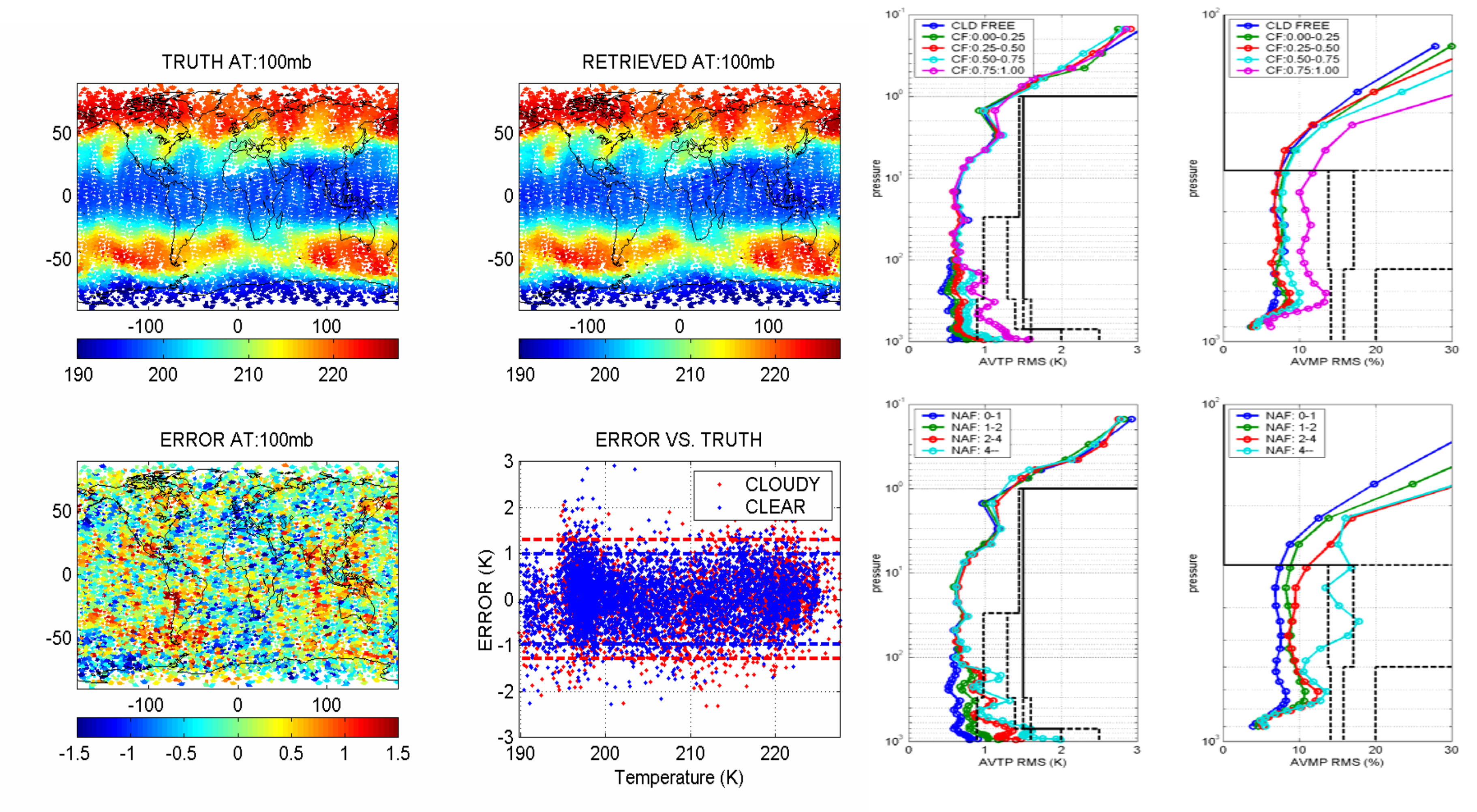

Summary

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- The CrIMSS EDR retrieval algorithm has demonstrated excellent performance on simulated test data
- The EDRs produced by the algorithm meet NPOESS/NPP EDR quality requirement specifications
- The algorithm also demonstrated promising performance on limited testing using the proxy test data derived from real AIRS/AMSU/HSB data